BIOMEDICAL ENGINEERING CURRICULUM:- A COMPARISON BETWEEN THE USA, EUROPE AND AUSTRALIA.

B. J. Lithgow.
Department of Electrical and Computer Systems Engineering, Monash University, Victoria, Australia

Abstract- **This paper compares Biomedical Engineering (BME) curricula in the USA, Europe and Australia. It reports on the shortcomings of the Australian curricula.**
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I. Introduction

"*One of the youngest disciplines in engineering, Biomedical Engineering is still rapidly evolving.......Perhaps it is time to rethink the philosophy of curriculum design in BME*. [1]" To develop a policy on Biomedical Engineering curriculum many factors must be taken into account. These include: historical perspective, current curriculum funding and policy; academic and research expertise, research funding, policy and infrastructure, government policy, overseas trends, internationalization and marketability of courses, commercialization of research, industry need, professional society accreditation, as well as, general student industry and professional society acceptance. This paper deals specifically with three of these inputs, namely, overseas trends, internationalization and marketability of courses all in the guise of curriculum development.

II. Methodology

Biomedical Engineering (BME) undergraduate (U/G) and postgraduate (P/G) Masters level course work curricula for 5-6 educational establishments in each of the USA, Europe and Australia have been collected from WEB sites together with research profiles for each of those establishments. WEB sites were targeted despite being potentially inacurate when compared with course handbook as these are the information sources commonly used by students, particularly international students, when selecting courses.

Selection of the educational establishments was based on:- (1). The existence of a well documented WEB site -- a curriculum and research profile being the minimum requirement; (2). Peer acknowledgment of each educational establishment as a reputable BME educator; (3). The desire to include in the USA at least 3 ABET approved courses; (4). The desire to include one representative of the European "Socrates" program[40]; (5). The desire to include one I.E. (Aust) accredited BME Degree program; (6). A desire to include representatives of the "better" (as determined by peer opinion) BME programs and; (7). The WEB site appearing to be up to date [3-20].

The Washington Accord provides for mutual recognition of Australian engineering programs in the USA, Ireland, UK, Canada, NZ, South Africa and Hong Kong [2]. Does this provide for significant overlap in course material and depth of presentation of that material?

III. Results

Table I lists the universities surveyed in this study [3-20]. In the USA and Australia undergraduate courses are common. There is a belief in Europe that BME is best taught as a postgraduate qualification. U/G course length is typically 4 years in the USA and 5 years in Australia. With the exception of University of Washington, all students enter the programs from senior high school. The US course is typically a BSE or BS and often is a precursor course to enter Medicine. The Australian course is typically BSc/BE or BE/M(BME)Eng combined degree. The US degrees are often stand alone in terms of employment opportunities. The Australian degrees tend to provide the graduate with employment opportunities both inside and outside the BME career path.

The percentages of each US U/G course that contain compulsory BME course work varies from 2 to 33%. The reason for this large variance is, for example, the opportunity provided by MIT and Northwestern Universities within thier course structure for students to undertake majors in life sciences related to BME rather than BME subjects. Physiology has traditionally been the life sciences component associated with BME U/G education courses. In the US the minimum compulsory physiology course content varies from 2-10% with MIT and Northwestern and to a lesser extent UCLA and Texas providing more freedom in course structure for the student to undertake alternative life sciences components. These alternative components may be more suited to a career in the area of genomics for example. The percentages of each Australian U/G course that contains compulsory BME course work varies from 0 to 25%. For the 5 year courses these percentages should be multiplied by 1.2 to equate then to the 4 year US courses. With the exception of the QUT program the Australian courses do not include as much compulsory BME material as Johns Hopkins, Washington or Texas Universities. The UNSW course has no BME component in the BE part of its combined degree only in the Masters component. Like the US courses the QUT course does not compromise the BME program to meet base BE degree requirements (e.g. Electrical engineering).

The P/G course content that is BME can vary from 0 to 100%. Courses such as those at Northwestern and Denmark are labeled BME but the subject offerings can be selected by students to gain a major in related biomedical areas. Generally the BME content can be described as being between 1/3 and 2/3 of the course content. Thesis content (where weighted in the course) typically represents 0-67% of the course. In the USA and Australia some universities replace the thesis by smaller projects or as at the UNSW or Texas A&M the thesis can be replaced by course work.

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The European (Riga) model is more strict, the minimum thesis content being 23%. The P/G physiology component can range from 0 (Strathclyde, Texas, Denmark and UNSW) to 36% at MIT. A course component of 10-20% is not uncommon at the Masters level. Some universities consider the physiology component to be an unweighted but compulsory U/G component.

Table I data show the USA courses have significantly more BME U/G and P/G course work subjects resulting in an increased diversity of subject options for students. However, the number of subjects (6-64) measure can be biased by having a large selection of smaller subjects or small selection of larger subjects. To provide further insight subject numbers were considered with respect to content and contact hours. The U/G programs are compared. The minimum number of BME subjects undergraduate hours (excluding thesis/final year project) in each of the 13 courses ranged from 36 to 690 contact hours. A course such as that at the University of Washington provides enormous flexibility, diversity and has a very large proportion of the course devoted to BME. However this course structure is uncommon. The second group (e.g. UCLA, Texas, Riga, and QUT) offer about half as many BME subjects and about 2/3 as many contact hours. These courses provide education programs specific to BME not compromised by base degree or combined degree requirements. The third group of courses, mostly Australian, (e.g.. UNSW, Monash and Swinburne) provide 5 year programs, the extra year allowing for a significant component of BME to be included within a base degree or combined degrees. The last group (e.g. Johns Hopkins, Northwestern, Latrobe and Flinders) provide a limited number of core BME subjects within their courses. The total BME subject hours allotted in these courses highlights this limitation. The MIT program has only one core BME subject within a very flexible course which includes very many BME subject options.

The process of analyzing courses in terms of subject content is often difficult. The difficulty arises from the use of broad descriptive subject titles, from the use of specific titles representing the most marketable components of a subject, from the variability in depth of subject coverage, from the lack of lecture detail available when only given a short subject synopsis, etc. These shortcomings can make some subject comparisons meaningless. For this reason for comparisons subjects were renamed to suit the generic subject area and subjects were omitted if not being truly BME.

Using the criterion that, an U/G subject area was common if at least half the regional universities taught that subject, the USA has 16, Europe 9 (only one course) and Australia 9 common subject areas. In the USA these U/G subject areas are biomechanics, BME electronics, *BME signal processing, BME maths, BME control systems, Biofluid dynamics*, biomaterials and artificial organs, *BME energy transfer*, *BME Seminars*, BME design project, physiology, BME instrumentation, *cellular and tissue engineering,* BME imaging and *BME modeling.* In Australia these are biomechanics, BME electronics, *clinical engineering*, biomaterials and artificial organs, BME design project, physiology, *biophysics*, BME instrumentation and BME imaging. The italicized subjects in the Australian list are not included in the USA list and vice versa. The italicized Australian subjects, one, reflect the historical overlap of Medical physics and BME and, two, that historically employment opportunities for biomedical engineers were in the clinical engineering sector [20]. The italicized USA subjects are a mixture of newer BME areas (e.g.. Cellular and tissue engineering), modeling and introduction to research (seminars). The Riga course profile is similar to those in Australia.

A similar analysis of P/G BME subject offerings for the 17 universities shows the USA courses have many more subjects on offer than the European or Australian courses. This may reflect their higher level of interaction with industry or strong links to research in those subject areas. The European Commission--Socrates Program in the, "*Tampere Recommendations on Education, Training and Accreditation in Medical Physics and Biomedical Engineering*" [26] have produced a framework for P/G BME education (eg. Tampere, Riga and Denmark). This traditional framework may constitute a significant limitation to course flexibility, particularly to the level current in the USA.

IV. Discussion

There are embryonic efforts by the *online symposium for electrical engineers* who are developing a "global electrical engineering including BME curriculum"[21]**.** The European community has recognized the need for cross country recognition of qualifications in BME. The Socrates program in its various guises has produced a number of templates for BME P/G courses.[17] However, the members of the Socrates program do not believe BME should be an U/G course and further believe that a good base in an Engineering is required first. Marketability of global U/G BME curricula to Europe seems unlikely.

Likewise given the diversity of P/G curricula and its obvious correlation to the research strengths of individual staff identification of whole curricula that is acceptable globally is unlikely. The ABET attitude is, "*we examine courses not for what they do not contain but for what they do contain"[22]*. The US attitude is one that, at the P/G level, students should be introduced to, as well as core areas, *"areas where industry is at"*, *"areas where employment is at"*. Taking the example of cellular and tissue engineering this subject area is being researched globally but taught BME curriculum wise predominantly in the USA. The general acceptance of the need for core units in P/G BME courses is waning in the US. For example, the MIT program offers 36 BME subjects of which only one is core. The area of BME has become so diverse that a student wishing to work in, for example, biomolecular engineering may need to concentrate on biochemistry and signal processing but have little use for bioelectronics (a core unit in many courses).

University	no. of BME subjects	min hrs of bme U/G excluding thesis	subjects used in hrs. calc.	comments	
Johns Hopkins [3]	34	204 (12 week term)	6 subjects	U/G	estimate
Washington [4]	40	690 (12 week term)	23 subjects (estimate)	U/G	"typical" estimate
UCSD [5]	64	588 (12 week term)	13 subjects	U/G	38+P/G COURSES
Northwestern [6]	46	216 (12 week term)	6 subjects	U/G	
MIT [7]	36	36 (12 week term)	1 subject	U/G	
Texas [8]	28	420 (12 week term)	11 subjects	U/G	
Strathclyde [9]	9+			no U/G course	
Imperial College [10]	11			no U/G course	medical or eng track
Tampere [11]	12			no U/G course	
Riga [12]	15	432 (12 week term)	15	U/G	vague research descriptions
Denmark [13]	6			no U/G course	
UNSW [14]	19 (3 Eng, 2 Physiol)	288 (12 week term)##	8 subjects	masters only##	
Monash [15]	11	288 (12 week term)	11 subjects	U/G	
Latrobe [16]	7 (3 of are biostats)	168 (12 week term)	4 subjects	U/G & P/G	
Swinburne [17]	7 (4 include physiology)	343 (12 week term)	' subjects (4 exclude 0.4 physiol component		U/G
Flinders [18]	7 plus projects	204 (12 week term)	4 subjects	U/G	
QUT [19]	13 plus projects	456 (12 week term)	8 subjects	U/G	

Table I: BME Course comparisons

The development of Australian P/G BME curricula would ideally be as flexible as that in the US. Constraining that freedom is cost. The use of core units limits teaching resources to a financially acceptable level. Small BME teaching staff numbers limits subject options especially those subjects wherein the lecturer has research experience. However, there are experts in Australia capable of delivering research level P/G courses in, for example, biomolecular engineering. While funding for these experts to deliver courses interstate is probably in short supply the development of distance learning modules should not be discounted, nor should a short term intensive laboratory component at a specialist institute for interstate students.

One of the major BME universities in Australia needs to develop a series of U/G and P/G subjects (perhaps using the distance education model or by importing expertise) in the new areas of BME (biomolecular engineeering, proteomics, genomics, cellular and tissue engineering....etc.). Overseas graduates are eagerly employed in these rapidly expanding billion dollar fields. Likewise, student awareness of research direction needs to be enhanced. In the US seminar programs are included as course work units. Given the difficult Australian demographics an alternative may be an annual BME research conference that becomes a course work unit. Perhaps there is also scope in Australia for an U/G course concentrating on these new and currently ignored BME areas.

In the USA the major BME educational institutions provide U/G programs with majors in each of biomolecular engineering, proteomics, genomics, cellular and tissue engineering....etc. Interestingly, this is despite the joint Entity Position Statement of the IEEE Educational Activities Board (EAB) and the IEEE - USA Board (USAB) that "*The U.S. system for the education and training of engineers, technologists, and technicians require the development of engineers with broad, holistic backgrounds and the capability to respond to rapid technology changes in a global environment [24].*"

Should the new growth areas of molecular and structural biology, bioinformatics, genomics, proteomics etc. be taught as BME subjects in Engineering faculties or by the Medical/Biochemistry Faculties of universities? Those at Johns Hopkins suggest:- "*The Cellular Bioengineering Pathway .... will prepare students for careers in academia or industry in which they will apply engineering expertise to questions in the basic science of cell biology or develop new engineering solutions for cell based technologies.*" [2]

How many of the courses are true BME courses? True, in the sense that the course contains real BME subjects, true in this sense that these subjects contain dedicated BME material, and true in the sense that students might expect to gain BME employment as a consequence of these courses. Many BME subjects descriptions hide the fact that these subjects are reductions (or sometimes not even reductions) of existing non BME course work subjects often delivered in parallel to non BME students by lecturers without biomedical backgrounds. In other words, these subjects contain little or no BME applications for laboratory exploration or lecture discussion. They cannot be delivered in a manner which allows for a life sciences or bioelectricity knowledge background. These pseudo BME subjects mean many of the U/G BME courses are little more than standard BE's with a couple of biomedical engineering options in the final year of study. Gerard Delanty's contention [25], that "*universities need to redefine accountability in a way that positions them at the heart of their social and civic communities*" seem highly appropriate.

The Australian requirement of 80 hrs of life sciences training beyond an engineering degree being the only requirement for full membership of the college of BME (and public recognition as a BME) appears grossly inadequate. Given the curriculum observations earlier in this report perhaps a better definition would suggest xxx hrs of recognized BME training in an area likely to facilitate an adequate grounding in at least one BME major. This generalized definition could then cite appropriate combinations of minimum numbers of hours in subject areas appropriate to the BME major.

In the Australian context does the above discussion point toward a good combination/approach being a BSc in the life sciences major and BE in the engineering major? If so why are there no double degrees wherein the BE component is a stand alone Bachelor of BME? Answer:-

- No one has produced compelling evidence (survey) re employment opportunities for graduates in Australia's fledgling BME Industry.
- Lack of knowledge of the extent or definition of the BME Industry -- Is it a global, partially global or local industry?
- Lack of long term planning or policy development by the BME Industry and BME professional societies.
- Traditional policies on course structure and funding -- Why can't engineering be a five year course? Why can't BME be a five year stand alone course? Why is it better to have a base degree in electrical engineering before studying BME?

Can we develop curricula for BME education in Australia with applicability to the global marketplace? If possible can we make that curricula compatible with global trends and expectations? "*A successful policy will result if this political process is effectively managed and the three criteria of desirability ...., work ability ...... and exceptability are satisfied* [23]."

V. CONCLUSIONs

- Australian P/G course work curricula in BME needs to include new areas of BME such as cellular and tissue engineering, biomolecular engineering, proteomics and genomics as well as include ignored areas of BME such as BME systems modeling.
- Current research directions needs to be introduced to students.
- At the U/G level a course appears needed and required by industry to supply biomedical engineers with base skills in biomolecular engineering, proteomics, genomics, cellular and tissue engineering....etc.).
- Ethical approaches to BME course and subject descriptions need to be applied to facilitate U/G students recognizing best BME programs.
- Flexible yet strict accreditation procedures need to be applied to BME courses.

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